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NITRAMINE PROPELLANT EROSIVITY - III

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December 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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This report is the third in a series on erosion measurements in a 37-mm blowout gun to compare the erosivity of propellants with RDX and HMX, denoted nitramines, with conventional double- and triple-base propellants.

In these tests, a series of nitramine, triple-base, and double-base propellants were formulated with equivalent flame temperatures; three such groups of

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20. ABSTRACT (continued)

propellants were made with flame temperatures of 2,700, 3,000 and 3,300 K. Closed-vessel measurements verified that the propellants manufactured at the LCWSL, Dover, NJ, conformed to thermochemical predictions made with the Blake thermochemical code.

Erosion measurements were made at two rupture pressures. The charge weight of each propellant was adjusted to give a closed-bomb pressure slightly above the rupture pressure. The results of the tests showed the propellants with similar flame temperatures yielded similar erosion; propellants with higher flame temperatures always eroded more metal. These results are in agreement with the earlier reports that the nitramines behave as conventional propellants regarding gun wear.

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I. INTRODUCTION

Nitramine propellants refer to propellants containing either of the cyclic nitramines, RDX or HMX. Solid propellants in the Army inventory are classified as single-base (nitrocellulose), double-base (nitrocellulose and nitroglycerin), or triple-base (nitrocellulose, nitroglycerin, and nitroguanidine). Nitramine propellants are being advocated to reduce barrel wear and to reduce the vulnerability of conventional propellants.

The case for nitramine propellants rests with the relatively low molecular weights of their combustion products which produces a lower adiabatic flame temperature for a given specific force. Nitramine propellants could replace conventional propellants either to get higher velocity with a given flame temperature or to keep the same velocity with a lower flame temperature. In other words, nitramine propellants behave like conventional propellants in that barrel wear is proportional to the adiabatic flame temperature[1]. Some experiments suggested, however, that nitramine propellants produced more wear than conventional propellants with similar flame temperatures[2,3]. More recent experiments[4,5] run to check this anomaly produced some mixed results, but led to the conclusion that the nitramine propellants behaved like conventional propellants. Caveny and co-workers[6] found an HMX/inert-binder propellant was more erosive than a single-base propellant with a similar flame temperature; preliminary results at Calspan Corporation also produced

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[1] *R. H. Greaves, H. H. Abram and S. H. Rees, "The Erosion of Guns", J. Iron and Steel Institute, 119, 113 (1929).*

[2] *"Hypervelocity Guns and the Control of Gun Erosion", Summary Technical Report of Division 1, National Defense Research Committee, Washington, DC, 1946.*

[3] *E. F. Boggs, B. A. Helman and R. P. Baumann, "High Force-Low Flame Temperature, Nitramine-Filled Propellants", Proceedings of the International Symposium on Gun Propellants, Picatinny Arsenal, Dover, NY, October 1973.*

[4] *R. W. Geene, J. R. Ward, T. L. Brosseau, A. Niiler, R. Birkmire and J. J. Rocchio, " Erosivity of a Nitramine Propellant", BRL Technical Report TR-02094, August 1978.* (AD #A060590)

[5] *J. R. Ward and R. W. Geene, "Erositivity of a Nitramine Propellant with Flame Temperature of M30 Propellant", BRL Memorandum Report No. 02926, June 1979.* (AD #A074346)

[6] *L. H. Caveny, A. Gany, S. O. Morris, M. Summerfield and J. W. Johnson, "Effect of Propellant Type on Steel Erosion", Proceedings of the 1978 JANNAF Propulsion Meeting, Incline Village, NV, February 1978.*

more wear with a nitramine propellant than M30 propellant despite the lower flame temperature for the nitramine propellant[7].

The tests reported here try to gather further data with nitramine propellants and their conventional propellant counterparts. The compositions of a double-base, triple-base, and nitramine propellant with similar flame temperatures were deduced with the Blake thermochemical code[8]. Compositions were determined at three flame temperatures, 2,700, 3,000, and 3,300 K for a total of nine propellants. The Large Caliber Weapon Systems Laboratory (LCWSL) manufactured a small lot of each propellant for testing. The peak pressure in a closed bomb was determined for each propellant to verify computed properties.

II. EXPERIMENTAL

A. Propellants

The compositions of the nine propellants designed with the BLAKE thermochemical code are listed in Tables 1-3. The grain dimensions and the heats of explosion were measured and supplied by the LCWSL manufacturer. The initials NA, TB, and DB refer to nitramine, triple-base, and double-base respectively; the integers 1, 2, and 3 denote 2,700, 3,000, and 3,300 K flame temperature, respectively. The compositions of other propellants fired in earlier tests are listed in Table 4.

The thermochemical properties of the propellants and the combustion gases produced with a 0.2-g/cm^3 loading density are listed in Tables 5 and 6 based on results with the BLAKE thermochemical code. The following information is provided:

- T - adiabatic flame temperature, K,
- F - specific force, J/g,
- η - co-volume, cm^3/g,
- M - average molecular weight of the combustion gases, g/mole,
- Cp - specific heat at constant pressure, J/mole,
- γ - ratio of specific heats.

The propellant gas compositions are also listed in units of moles of gas per kilogram of propellant.

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[7] *F. Vassallo, private communication, report in preparation.*

[8] *E. Freedman, "BLAKE - A Ballistic Thermodynamic Code Based on TIGER", Proceedings of the International Symposium on Gun Propellants, Picatinny Arsenal, Dover, NJ, October 1973.*

TABLE 1. COMPOSITIONS AND GRAIN DIMENSIONS OF THE NITRAMINE PROPELLANTS

Composition (percent by weight)	NA-1	NA-2	NA-3
Nitrocellulose (12.6% N)	30.0	30.0	30.0
Nitroglycerin	15.6	18.3	21.1
RDX	41.5	41.5	41.5
Ethyl centralite	1.5	1.5	1.5
Dioctylphthalate	11.2	8.5	5.7
Residual alcohol	0.2	0.2	0.2
Dimensions			
Length, mm	7.26	9.09	10.90
Diameter, mm	1.78	2.21	2.67
Inner diameter, mm	0.66	0.84	0.99
Web, mm	0.56	0.69	0.84
Heat of explosion, J/g	3454	3869	4308

TABLE 2. COMPOSITIONS AND GRAIN DIMENSIONS OF THE TRIPLE-BASE PROPELLANTS

Composition (percent by weight)	TB-1	TB-2	TB-3
Nitrocellulose (12.6% N)	27.4	27.4	27.4
Nitrogylcerin	11.0	22.0	33.0
Nitroguanidine	59.6	48.6	37.6
Ethyl centralite	1.5	1.5	1.5
Sodium cryolite	0.3	0.3	0.3
Residual alcohol	0.2	0.2	0.2
Dimensions			
Length, mm	7.06	9.80	11.60
Diameter, mm	1.68	2.1	2.50
Inner diameter, mm	0.71	0.84	1.00
Web, mm	0.41	0.64	0.74
Heat of explosion, J/g	3622	3906	4375

TABLE 3. COMPOSITIONS AND GRAIN DIMENSIONS OF THE DOUBLE-BASE PROPELLANTS

Composition (percent by weight)	DB-1	DB-2	DB-3
Nitrocellulose (13.25% N)	66.6	69.8	73.2
Nitroglycerin	20.0	20.0	20.0
Barium nitrate	1.4	1.4	1.4
Potassium nitrate	0.7	0.7	0.7
Ethyl centralite	11.1	7.9	4.5
Residual alcohol	0.2	0.2	0.2
Dimensions			
Length, mm	7.82	9.68	11.90
Diameter, mm	2.00	2.41	2.97
Inner diameter, mm	0.84	1.04	1.27
Web, mm	0.57	0.69	0.85
Heat of explosion, J/g	3417	3793	4229

TABLE 4. COMPOSITIONS AND GRAIN DIMENSIONS OF PROPELLANTS FIRED IN THE EARLIER NITRAMINE EROSION TESTS

Composition (percent by weight)	M30C2	NT PPL-A-6396	M30 PPL-A-6372	HFP PPL-A-6380
Nitrocellulose (12.6%N)	26.6%	28.5%	28.0%	29.3%
Nitroglycerin	21.4	20.5	22.5	22.7
Nitroguanidine	45.3	7.00	47.7	5.0
RDX	-	34.5	-	36.5
Dioctylphthalate	-	8.00	-	5.0
Ethyl Centralite	1.4	1.50	1.5	1.5
Cryolite	0.3	-	0.3	-
Total Volatiles, residual	-	0.3	0.2	0.3
Dimensions				
Grain Length, mm	-	10.46	7.78	10.58
Grain Diameter, mm	-	2.48	1.59	2.57
Grain Perf. Diameter, mm	-	0.831	0.46	0.77
Grain Web, mm	-	0.826	0.56	0.80
Grain Geometry	SP	SP	SP	SP

TABLE [illegible] COMPOSITIONS AND GRAIN DIMENSIONS OF PROPELLANTS
[illegible] IN THE EARLIER NITRAMINE EROSION TESTS (CONT'D)

Composition (percent by weight)	M5	M8	M1
Nitrocellulose (13.25%N)	81.95%	52.15%	85.00%
Nitroglycerin	15.00	43.00	-
Ethyl Centralite	0.60	0.60	-
Barium Nitrate	1.40	-	-
Potassium Nitrate	0.75	1.25	-
Diethylphthalate	-	3.00	-
Dinitrotoluene	-	-	10.00
Dibutylphthalate	-	-	5.00
Diphenylamine, Added	-	-	1.00
Ethyl Alcohol, Residual	2.30	0.40	0.75
Water, Residual	0.70	-	0.50
Graphite	0.30	-	-
Dimensions			
Grain Length, mm	10.58	25.4	8.28
Grain Diameter, mm	3.92	-	3.68
Grain Perf. Diameter, mm	0.41	-	0.37
Grain Web, mm	0.69	0.56	0.64
Grain Geometry	7 Perf	Strip	7 Perf

TABLE 5. THERMOCHEMICAL PROPERTIES OF PROPELLANTS LISTED IN TABLES 1, 2, and 3

Propellant	T,K	F,J/g	η,cm^3/g	M,g/mole	Principal Composition of Combustion Gases, moles/kg: CO	CO_2	H_2O	H_2	N_2	C_p,J/mole	γ
DB-1	2,705	991	1.084	22.7	21.3	2.6	6.8	8.2	4.9	41.8	1.26
TB-1	2,698	1,007	1.087	22.3	12.1	2.2	9.4	7.6	13.4	42.5	1.25
NA-1	2,709	1,078	1.151	20.9	20.4	1.6	6.1	11.1	8.0	40.6	1.26
DB-2	2,994	1,046	1.043	23.8	19.0	3.5	8.2	6.0	5.0	43.5	1.24
TB-2	3,004	1,075	1,052	23.2	11.7	2.9	10.5	5.6	12.1	44.0	1.24
NA-2	3,002	1,143	1.112	21.8	18.7	2.1	7.6	9.2	8.2	42.0	1.25
DB-3	3,297	1,093	1.003	25.1	16.3	4.8	9.4	4.0	5.0	45.6	1.23
TB-3	3,304	1,133	1.018	24.2	11.1	3.9	11.2	4.0	10.7	45.6	1.23
NA-3	3,307	1,200	1.071	22.9	16.7	2.8	8.9	6.7	8.4	43.5	1.24

TABLE 6. SUMMARY OF THERMOCHEMICAL PROPERTIES OF PROPELLANTS LISTED IN TABLE 4

Prop	T,K	F,J/g	η,cm^3/g	M,g/mole	Principal Composition of Combustion Gases, moles/kg CO	CO_2	H_2O	H_2	N_2	C_p,J/mole	γ
M30C2*	2710	972	1.051	23.2	12.5	2.8	9.7	6.2	11.5	43.3	1.25
M30(PPL-A-6372)	3021	1,078	1.050	23.3	11.8	3.0	10.5	5.5	11.9	41.1	1.24
NT-6296	2954	1,126	1.109	21.8	18.0	2.1	7.8	9.1	8.6	42.0	1.25
M5**	3264	1,079	1.003	25.1	16.5	4.9	9.3	4.0	4.9	45.5	1.23
HFP(PPL-A-6380)	3301	1,192	1.066	23.0	16.0	2.9	9.2	6.4	8.7	43.7	1.24
M8**	3716	1,178	0.970	26.2	13.0	6.4	10.2	2.4	5.4	47.7	1.22
M1	2480	928	1.108	22.2	22.8	2.4	6.1	9.1	4.5	41.0	1.27

M30 propellant modified with five percent of a calcium salt.

***Based on nominal composition.*

Tables 5 and 6 reveal interesting chemical differences among the combustion gases. The triple-base propellants produce significantly less carbon monoxide and higher amounts of water and nitrogen relative to the double-base and nitramine formulations. The lower molecular weights produced by the nitramine propellants arise from reduction of carbon dioxide and production of hydrogen.

B. Wear Measurements

The wear produced by a given propellant was determined by mass loss from a contoured nozzle in the 37-mm "blowout" gun as was done in the two earlier reports[4,5].

The blowout gun consists of the breech and chamber of a 37-mm gun with the barrel severed just before the forcing cone. A fitting was adapted to the barrel to hold the nozzle and the rupture disks. A pressure-gage was placed at mid-chamber to obtain pressure-time data. A schematic of the blowout gun appears in earlier reports[4,5]. The development of the blowout gun is recorded in references 9-11.

The shape of the contoured nozzle evolved from early experiments[12] with cylindrical nozzles in which the mass loss per shot became constant after the cylindrical nozzle was worn to the shape also depicted in references 4 and 5. The nozzle was made from AISI 4140 steel.

After each firing the nozzle was brushed with a commercial cleanser containing a mild abrasive, rinsed with soap and water, and dried. The nozzle was weighed on an Ainsworth "Right-a-way" analytical balance. With care, the mass loss could be measured within 0.1 mg. To achieve this precision, the balance was zeroed, the nozzle weighed, and the zero checked for drift. This sequence was repeated until two nozzle readings agreed within 0.1 mg and the zero did not change. The following illustrates a typical sequence of weighings.

---

[9] C. H. Wiegand, *"Erosion in Vent Plugs", BRL Report No. 550, [illegible].*

[10] C. H. Wiegand, *"Erosion in Vent Plugs-II-The Effect of Vent Shape and Metal", BRL Report 578, January 1946.*

[11] C. H. Wiegand and B. B. Grollman, *"Experiments on the Burning of Powder in a Blowout Chamber", BRL Report No. 588, November 1945.*

[12] [illegible] Jones and E. R. Weiner, *"Experiments on the Erosion of Steel by the Vent Technique", BRL Report 1012, March 1957.* (AD #135507)

Weighing	Mass, g
1	125.5207 zero drifted
2	125.5210 zero drifted
3	125.5211
4	125.5211
reported nozzle mass	125.5211

The care taken during weighing is mentioned to show error in weighing is not the reason for the previously observed[4,5] deviations in mass loss repeatability. Blank experiments were also done to show a nozzle could be repeatedly washed, dried, and weighed with the nozzle mass remaining within 0.1 mg.

The rupture disks were punched from 14-gauge, hot-rolled steel (AISI A415). The measured disk thickness ranged from 1.73 to 1.75 mm (0.068-0.069 in); Brinell hardness measurements on the disk surface ranged from 110 to 116. The initial experiments[4] used 16-gauge, cold-rolled steel (A366) which had a Brinell hardness less than 100; the 16-gauge disks were 1.54 mm (0.060 in) thick. The combination of physical properties and disk thickness produced a range of rupture pressures as illustrated below.

Number of Disks	Rupture Pressure, MPa A366 (1.54 mm)	Rupture Pressure, MPa A415 (1.75 mm)
2	193	248
3	283	324
4	413	-

Charge weights were determined by computing the propellant mass required to give 303 MPa (44 kpsi) for two shear disks and 393 MPa (57 kpsi) for three shear disks to insure sufficent gas was generated to shear the disks cleanly and reproducibly.

The charges were ignited with M1B1A2 percussion primers except where noted.

III. RESULTS

The peak pressures measured in a closed vessel are summarized in Table 7 along with the impetus calculated from the following:

$$F = P\left(\frac{1}{\Delta} - \eta\right) \qquad (1)$$

TABLE [illegible]. SUMMARY OF CLOSED BOMB MEASUREMENTS*

Propellant	Δ, g/cm³	P_{max} expt'l, MPa	η, cm³/g	I, expt'l, J/g	I, cal'd, J/g	Δt, ms**
DB-1	0.198	248.1	1.084	984	991	4.3
TB-1	0.198	252.6	1.087	1,001	1,007	5.2
NA-1	0.198	269.9	1.151	1,052	1,078	5.7
DB-2	0.198	260.5	1.043	1,044	1,046	5.8
TB-2	0.199	267.5	1.052	1,063	1,075	4.7
NA-2	0.199	288.5	1.112	1,129	1,143	5.1
DB-3	0.198	270.6	1.003	1,095	1,093	4.1
TB-3	0.199	280.2	1.018	1,123	1,133	5.1
NA-3	0.198	300.5	1.071	1,196	1,200	4.7

*Closed bomb free volume is 197.8 cm³; temperature 294K in all runs.

**Time from 13.8 MPa to P_{max}.

where

F = specific force or impetus, J/g,

Δ = loading density, g/cm^3,

η = co-volume, cm^3/g,

P = maximum pressure, MPa.

The agreement between the experimental impetus and the impetus computed from the BLAKE thermochemical code shows the propellant manufactured at the LCWSL conforms to the composition specified.

The firing record for this test series is placed in Appendix A, while Appendix B illustrates pressure-time curves for the propellants tested. A new nozzle was used for each propellant. Tables 8, 9 and 10 summarize the wear measurements for the nine propellants at each rupture pressure. The mean mass loss per shot and sample standard deviation are computed along with the slope and the intercept determined from a linear least-squares fit of the mass losses vs shot fired. In general the slope of the linear least-squares line agrees with the mean mass loss. A similar observation was made in the first two test series[4,5].

Tables 11 and 12 collect the sample means and standard deviations. By inspection one sees erosion increases with flame temperature and is independent of the type of propellant for a given flame temperature. One exception might be NA-2 which might be higher than DB-2 or TB-2 at 324 MPa. Nonetheless, the erosion from NA-2 is still below the erosion produced by the three 3,300 K propellants, and NA-2 produced comparable erosion to DB-2 and TB-2 at 248 MPa. One must temper conclusions drawn from the 248 MPa results because of the relatively large standard deviations compared to the mean erosion rate.

Tables 13 and 14 summarize the erosion results with other propellants tested.

TABLE 8. SUMMARY OF EROSION MEASUREMENTS FOR DB-1, TB-1, AND NA-1

Sample No.	DB-1 erosion, mg 248 MPa	DB-1 erosion, mg 324 MPa	TB-1 erosion, mg 248 MPa	TB-1 erosion, mg 324 MPa	NA-1 erosion, mg 248 MPa	NA-1 erosion, mg 324 MPa
1	2.4	1.8	5.0	3.2	2.6	1.5
2	3.5	2.3	3.1	2.5	1.8	2.0
3	1.5	2.3	2.7	1.1	2.2	0.3
4	2.1	-	3.1	-	1.3	-
5	1.5	-	2.2	-	3.7	-
6	1.5	-	2.5	-	1.1	-
7	1.7	-	3.2	-	2.6	-
8	1.7	-	1.9	-	2.4	-
9	1.6	-	2.4	-	1.3	-
10	1.2	-	2.3	-	1.4	-
11	1.5	-	-	-	1.2	-
12	1.4	-	-	-	1.8	-
13	0.8	-	-	-	1.6	-
14	-	-	-	-	1.6	-
15	-	-	-	-	1.9	-
16	-	-	-	-	1.1	-
slope, mg/shot	1.6	-	2.6	-	1.[illegible]	-
intercept	2.5	-	3.0	-	1.[illegible]	-
mean, mg/shot	1.7	2.1	2.8	2.3	1.9	1.5
std dev	0.7	0.3	0.9	1.0	0.7	0.9
charge mass, g	75	91	74	90	70	85

TABLE 9. SUMMARY OF EROSION MEASUREMENTS FOR DB-2, TB-2, AND NA-2

Sample No.	DB-2 erosion, mg 248 MPa	DB-2 erosion, mg 310 MPa	TB-2 erosion, mg 248 MPa	TB-2 erosion, mg 331 MPa	NA-2 erosion, mg 248 MPa	NA-2 erosion, mg 331 MPa
1	4.2	3.4	5.5	3.3	2.3	10.7
2	3.0	5.0	2.8	5.2	1.8	7.1
3	3.1	3.7	2.9	4.8	1.6	4.0
4	2.3	4.3	2.9	3.7	2.2	5.6
5	4.2	3.3	3.1	3.3	3.7	8.1
6	3.1	-	4.1	-	2.4	-
7	2.0	-	3.0	-	2.4	-
8	2.9	-	2.1	-	2.8	-
9	1.6	-	2.1	-	0.5	-
10	3.2	-	4.2	-	3.1	-
11	3.0	-	2.9	-	4.0	-
12	2.8	-	3.7	-	3.9	-
13	2.3	-	2.2	-	2.2	-
14	2.2	-	2.3	-	2.2	-
15	1.9	-	2.3	-	2.4	-
16	2.5	-	3.0	-	2.5	-
17	2.4	-	2.8	-	2.7	-
slope, mg/shot	2.7	4.1	2.9	4.2	2.6	5.9
intercept	2.7	-0.2	2.9	-0.3	-1.7	4.9
mean, mg/shot	2.8	3.9	3.0	4.1	2.5	7.1
std dev	0.7	0.7	0.9	0.9	0.9	2.5
charge mass, g	73	85	71	87	68	82

TABLE 10. SUMMARY OF EROSION MEASUREMENTS FOR DB-3, TB-3, AND NA-3

Sample No.	DB-3 erosion, mg 248 MPa	DB-3 erosion, mg 324 MPa	TB-3 erosion, mg 248 MPA	TB-3 erosion, mg 324 MPa	NA-3 erosion, mg 248 MPa	NA-3 erosion, mg 324 MPa
1	2.2	14.9	3.1	17.5	2.2	13.5
2	1.9	12.2	3.0	10.7	2.6	16.9
3	3.1	12.6	3.5	9.4	1.8	13.2
4	3.3	13.6	2.3	10.1	2.4	16.0
5	2.1	9.7	1.4	12.2	2.4	7.5
6	1.5	17.3	3.8	10.5	2.5	8.5
7	4.1	-	3.4	-	3.4	-
8	3.6	-	4.4	-	4.7	-
9	5.2	-	3.1	-	3.7	-
10	3.3	-	7.7	-	3.9	-
11	4.2	-	4.0	-	2.8	-
12	3.9	-	3.7	-	4.6	-
13	5.9	-	5.0	-	5.7	-
14	5.8	-	7.2	-	6.0	-
15	5.0	-	5.4	-	6.1	-
slope, mg/shot	3.8	12.8	4.1	10.6	3.7	12.4
intercept	-5.3	1.6	-4.9	6.6	-5.5	4.6
mean, mg/shot	3.7	13.9	4.1	11.7	3.6	12.6
std deviation	1.4	2.9	1.7	3.0	1.5	3.9
charge mass, g	71	87	69	84	65	80

TABLE 11. WEAR MEASURED AT 248 MPa RUPTURE PRESSURE*

	Double-Base	Triple-Base	Nitramine
1	1.7 ± 0.7	2.8 ± 0.9	1.9 ± 0.7
2	2.8 ± 0.7	3.0 ± 0.9	2.5 ± 0.5
3	3.7 ± 1.4	4.1 ± 1.7	3.6 ± 1.5

**Wear in mg/shot; error given as sample standard deviation.*

TABLE 12. WEAR MEASURED AT 324 MPa RUPTURE PRESSURE*

	Double-Base	Triple-Base	Nitramine
1	2.1 ± 0.3	2.3 ± 1.0	1.3 ± 0.9
2	3.9 ± 0.7	4.1 ± 0.9	7.1 ± 2.5
3	13.9 ± 2.9	11.7 ± 3.0	12.6 ± 3.9

**Wear measured in mg/shot; error given as sample standard deviation.*

TABLE 13. SUMMARY OF EROSION MEASUREMENTS FOR OTHER PROPELLANTS*

Sample No.	M5 lot 480-11 248 MPa	M5 lot 480-11 331 MPa	M5 lot RAD 65492 331 MPa	HFP lot PPL-A-6260 248 MPa	M30 310 MPa	M30C2 317 MPa
1	8.0	40.5	46.7	1.4	7.4	2.2
2	5.9	35.5	38.6	3.5	5.2	2.1
3	6.7	34.9	45.4	2.5	6.9	2.7
4	-	35.7	46.4	0.8	5.9	2.8
5	-	-	-	1.6	6.6	3.5
6	-	-	-	1.4	9.9	3.4
Propellant class	DB-3	DB-3	DB-3	NA-3	TB-2	TB-1
slope, mg/shot	6.3	35.3	43.7	1.8	6.8	2.9
intercept	1.6	5.2	0.7	0.7	-0.5	-1.3
mean, mg/shot	6.9	36.7	44.3	1.9	7.0	2.8
std dev	1.1	2.6	3.9	1.0	1.6	0.6
mass, g	68	89	89	66	86	94
nozzle no.	40	40	31	39	38	31

*Erosion expressed in mg.

TABLE 14. SUMMARY OF EROSION MEASURED IN EARLIER TESTS

Prop	Erosion, mg Mean	std dev.	Shots	Mass, g	Rupture Pressure, MPa
M1	1.5	0.6	12	70	193
M1	0.8	0.3	8	70	193
M1	0.8	0.3	3	86	283
M30	2.9	0.9	12	58	193
M30	2.3	0.6	7	65	248
M30	3.5	1.3	3	75	283
M30	23.8	-	1	100	413
NT-6396	2.4	0.9	10	63	248
M5	5.0	1.7	12	60	193
M5	5.2	0.8	6	60	193
M5	4.0	0.4	4	60	193
M5	8.2	1.1	3	68	248
M5	25.9	0.9	2	77	283
M5	116.4	-	1	100	413
HFP	3.1	1.0	12	54	193
HFP	7.1	0.2	3	70	283
HFP	42.9	-	1	90	413
M8	17.7	4.2	12	54	193
M8	60.8	12	3	69	283
M8	306.5	-	1	100	413

The erosion results for propellants with similar flame temperatures, compositions, and rupture pressures are collected below:

Propellant	Erosion, mg/shot 248 MPa	Erosion, mg/shot 324 MPa
M6CE2		2.8 ± 0.6
DB-1		2.3 ± 1.0
M30	2.3 ± 0.6	7.0 ± 1.6
DB-2	3.0 ± 0.9	4.1 ± 0.9
NI-6396	2.4 ± 0.9	
NA-2	2.5 ± 0.5	
M5	6.9 ± 1.1; 8.2 ± 1.1	36.7 ± 2.6; 44.3 ± 3.9
DB-3	3.7 ± 1.4	13.9 ± 2.9
HFP	1.9 ± 1.0	
NA-3	3.6 ± 1.5	

In general, the other propellants fall in line with the nine propellants tested in this series, with the glaring exception of M5. Two separate lots of M5 were tested at 324 MPa to confirm the higher wear rate relative to the other propellants with a 3,300-K flame temperature. To further illustrate that the M5 anomaly is not confined to measurements at two rupture pressures, Figure 1 displays a semi-log plot of wear vs rupture pressure for M30, HFP, M5, and M8 propellants where one sees M5 also falls above HFP consistently. It is uncertain why M5 produces higher wear rates than HFP or DB-3, but it is clear that the difference is not the result of a careless experiment at a given rupture pressure.

IV. CONCLUSIONS

1. The erosivity of three nitramine, double-base, and triple-base propellants each with a flame temperature of 2,700, 3,000 and 3,300 K were measured in a blowout gun. For a given flame temperature, the erosivity increased with flame temperature.

2. The erosivity of M5 propellant was measureably higher than all other propellants with the same flame temperature. No explanation exists for the difference at this time.

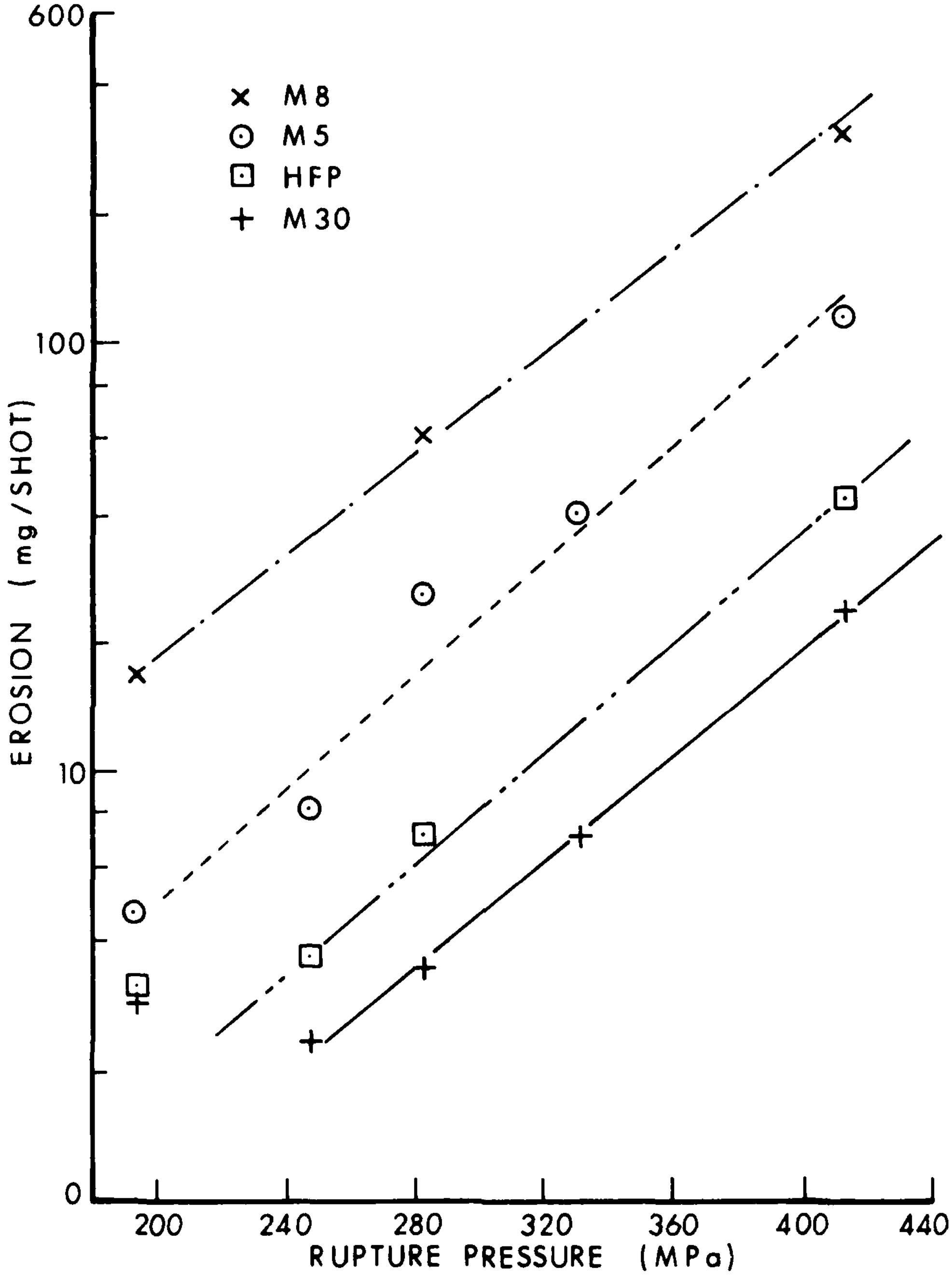

Figure 1. Wear Loss vs Rupture Pressure for Various Propellants

ACKNOWLEDGEMENTS

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APPENDIX A.
FIRING SEQUENCE FOR EROSION STUDY

FIRING SEQUENCE FOR EROSION STUDY

Date	Shot No.	Sample No.	Nozzle No.	Propellant	Charge mass, g	Note
13 Dec 78	1	-	31	M5 (480-11)	68	Checkout 12.3 mg eroded
	2	-	31	M5 (480-11)	68	Checkout 10.2 mg eroded
18 Dec 78	3	-	31	NA-1	70	Checkout 3.3 mg eroded
	4	1	33(new)	NA-1	70	
	5	2	33	NA-1	70	
	6	3	33	NA-1	70	
	7	4	33	NA-1	70	
	8	1	34(new)	DB-1	75	
	9	1	35(new)	TB-1	74	
	10	5	33	NA-1	70	
	11	2	34	DB-1	75	
	12	2	35	TB-1	74	
	13	6	33	NA-1	70	
	14	3	34	DB-1	75	
	15	3	35	TB-1	74	
	16	7	33	NA-1	70	
	17	4	34	DB-1	75	
	18	4	35	TB-1	74	
	19	8	33	NA-1	70	
19 Dec 78	20	5	34	DB-1	75	
	21	5	35	TB-1	74	
	22	9	33	NA-1	70	
	23	6	34	DB-1	75	
	24	6	35	TB-1	74	
	25	10	33	NA-1	70	
	26	7	34	DB-1	75	
	27	7	35	TB-1	74	
	28	11	33	NA-1	70	
	29	8	34	DB-1	75	
	30	8	35	TB-1	74	
	31	12	33	NA-1	70	
	32	9	34	DB-1	75	
	33	9	35	TB-1	74	
	34	13	33	NA-1	[illegible]	

FIRING SEQUENCE FOR EROSION STUDY (Cont'd)

Date	Shot No.	Sample No.	Nozzle No.	Propellant	Charge mass, g	Note
19 Dec 78	35	10	34	DB-1	75	
	36	10	35	TB-1	74	
	37	14	33	NA-1	70	
	38	11	34	DB-1	75	
	39	15	33	TB-1	70	
	40	12	34	NA-1	75	
	41	16	33	DB-1	70	
	42	13	34	TB-1	75	
20 Dec 79	43	1	36(new)	NA-2	68	
	44	1	37(new)	DB-2	73	
	45	1	38(new)	TB-2	71	
	46	2	36	NA-2	68	
	47	2	37	DB-2	73	
	48	2	38	TB-1	71	
	49	3	36	NA-2	68	
	50	3	37	DB-2	73	
	51	3	38	TB-2	71	
	52	4	36	NA-2	68	
	53	4	37	DB-2	73	
	54	4	38	TB-2	71	
	55	5	36	NA-2	68	
	56	5	37	DB-2	73	
	57	5	38	TB-2	71	
	58	6	36	NA-2	68	
	59	6	37	DB-2	73	
	60	6	38	TB-2	71	
5 Jan 79	61	7	31	NA-2	68	Checkout rd
	62	7	36	NA-2	68	
	63	7	37	DB-2	73	
	64	8	38	TB-2	71	
	65	8	36	NA-2	68	
	66	8	37	DB-2	73	
	67	8	38	TB-2	71	

FIRING SEQUENCE FOR EROSION STUDY (Cont'd)

Date	Shot No.	Sample No.	Nozzle No.	Propellant	Charge mass, g	Note
8 Jan 79	68	9	36	NA-2	68	
	69	9	37	DB-2	73	
	70	9	38	TB-2	71	
	71	10	36	NA-2	68	
	72	10	37	DB-2	73	
	73	10	38	TB-2	71	
	74	11	36	NA-2	68	
	75	11	37	DB-2	73	
	76	11	38	TB-2	71	
	77	12	36	NA-2	68	
	78	12	37	DB-2	73	
	79	12	38	TB-2	71	
9 Jan 79	80	1	39(new)	NA-3	65	
	81	1	40(new)	DB-3	71	
	82	1	41(new)	TB-3	69	
	83	2	39	NA-3	65	
	84	2	40	DB-3	71	
	85	2	41	TB-3	69	
	86	3	39	NA-3	65	
	87	3	40	DB-3	71	
	88	3	41	TB-3	69	
	89	4	39	NA-3	65	
	90	4	40	DB-3	71	
	91	4	41	TB-3	69	
	92	5	39	NA-3	65	
	93	5	40	DB-3	71	
10 Jan 79	94	1	40	M5 (480-11)	68	M38B2 primers used in shots 94-105
	95	2	40	M5 (480-11)	68	
	96	3	40	M5 (480-11)	73	
	97	1	39	NT (PPL-A-6260)	66	
	98	2	39	NT	66	
	99	3	39	NT	66	
	100	4	39	NT	66	

FIRING SEQUENCE FOR EROSION STUDY (Cont'd)

Date	Shot No.	Sample No.	Nozzle No.	Propellant	Charge mass, g	Note
11 Jan 79	101	5	39	NT	66	
	102	6	39	NT	66	
	103	5	41	TB-3	69	
	104	6	39	NA-3	65	
	105	6	40	DB-3	71	
	106	6	41	TB-3	69	
	107	7	39	NA-3	65	
	108	7	40	DB-3	71	
	109	7	41	TB-3	69	
	110	8	39	NA-3	65	
	111	8	40	DB-3	71	
	112	8	41	TB-3	69	
	113	9	39	NA-3	65	
	114	9	40	DB-3	71	
	115	9	41	TB-3	69	
	116	10	39	NA-3	65	
	117	10	40	DB-3	71	
	118	10	41	TB-3	69	
2 Feb 79	119	11	39	NA-3	65	
	120	11	40	DB-3	71	
	121	11	41	TB-3	69	
	122	12	39	NA-3	65	
	123	12	40	DB-3	71	
	124	12	41	TB-3	69	
	125	13	39	NA-3	65	
	126	13	40	DB-3	71	
	127	13	41	TB-3	69	
	128	14	39	NA-3	65	
	129	14	40	DB-3	71	
	130	14	41	TB-3	69	
	131	15	39	NA-3	65	
	132	15	40	DB-3	71	
	133	15	41	TB-3	69	
	134	14	36	NA-2	68	
	135	15	37	TB-2	73	
	136	15	38	TB-2	71	
	137	15	36	NA-2	68	

FIRING SEQUENCE FOR EROSION STUDY (Cont'd)

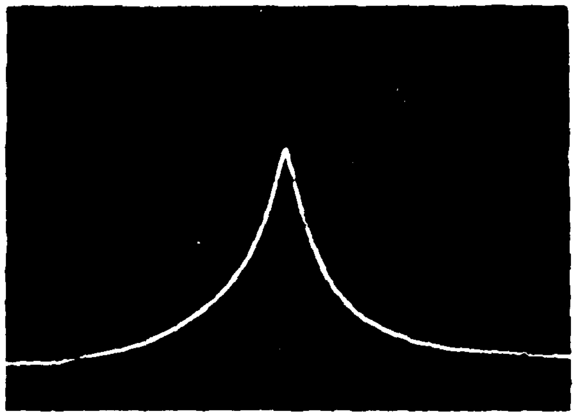
Date	Shot No.	Sample No.	Nozzle No.	Propellant	Charge mass, g	Set
2 Feb 79	138	14	37	DB-2	73	
	139	14	38	TB-2	71	
	140	16	36	NA-2	68	
	141	15	37	DB-2	73	
	142	15	38	TB-2	71	
5 Feb 79	143	17	36	NA-2	68	
	144	16	37	DB-2	73	
	145	16	38	TB-2	71	
	146	18	36	NA-2	68	
	147	17	37	DB-2	73	
	148	17	38	TB-2	71	
	149	1	36	NA-2	82	
	150	1	37	DB-2	85	
	151	1	38	TB-2	87	
	152	2	36	NA-2	82	
	153	2	37	DB-2	85	
	154	2	38	TB-2	87	
	155	3	36	NA-2	82	
	156	3	37	DB-2	85	
	157	3	38	TB-2	87	
	158	4	36	NA-2	82	
	159	4	37	DB-2	85	
	160	4	38	TB-2	87	
	161	5	36	NA-2	82	
	162	5	37	DB-2	87	
	163	5	38	TB-2	85	
15 Feb 79	164	1	39	NA-3	80	
	165	1	40	DB-3	87	
	166	1	41	TB-3	84	
	167	2	39	NA-3	80	
	168	2	40	DB-3	87	
	169	2	41	TB-3	84	
	170	3	39	NA-3	80	
	171	3	40	DB-3	87	
	172	3	41	TB-3	84	
	173	4	39	NA-3	80	

FIRING SEQUENCE FOR EROSION STUDY (Cont'd)

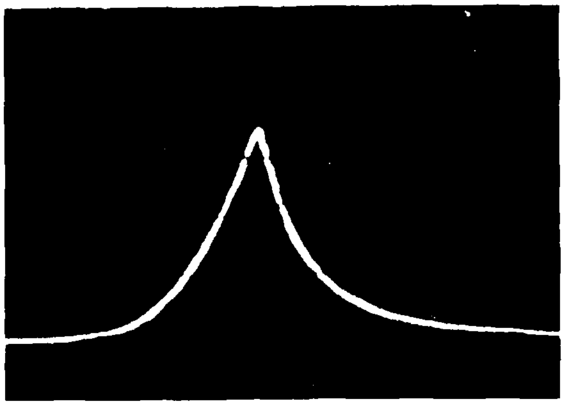
Date	Shot No.	Sample No.	Nozzle No.	Propellant	Charge mass, g	Note
15 Feb 79	174	4	40	DB-3	87	
	175	4	41	TB-3	84	
	176	5	39	NA-3	80	
	177	5	40	DB-3	87	
	178	5	41	TB-3	84	
	179	6	39	NA-3	80	
	180	6	40	DB-3	87	
	181	6	41	TB-3	84	
	182	1	33	NA-1	85	
	183	1	34	DB-1	91	
	184	1	35	TB-1	90	
	185	2	33	NA-1	85	
	186	2	34	DB-1	91	
	187	2	35	TB-1	90	
	188	3	33	NA-1	85	
	189	3	34	DB-1	91	
	190	3	35	TB-1	90	
16 Feb 79	191	1	31	M5	89	
	192	1	40	M5 (480-11)	89	
	193	2	31	M5	89	
	194	2	40	M5 (480-11)	89	
	195	3	31	M5	89	
	196	3	40	M5 (480-11)	89	
	197	4	31	M5	89	
	198	4	40	M5 (480-11)	89	
28 Feb 79	199	1	31	M30C2	94	
	200	1	38	M30	86	
	201	2	31	M30C2	94	
	202	2	38	M30	86	
	203	3	31	M30C2	94	
	204	3	38	M30	86	
	205	4	31	M30C2	94	
	206	4	38	M30	86	
	207	5	31	M30C2	94	
	208	5	38	M30	86	
	209	6	31	M30C2	94	
	210	6	38	M30	86	

APPENDIX B.
Pressure vs Time for Each Propellant Fired in this Test Series.

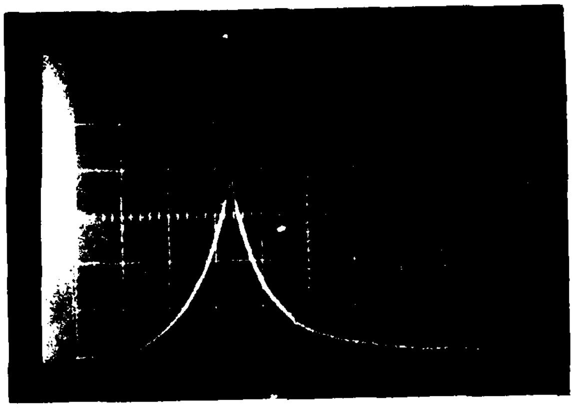
[69 MPa per division (vertical)]
[2 ms per division (horizontal)]



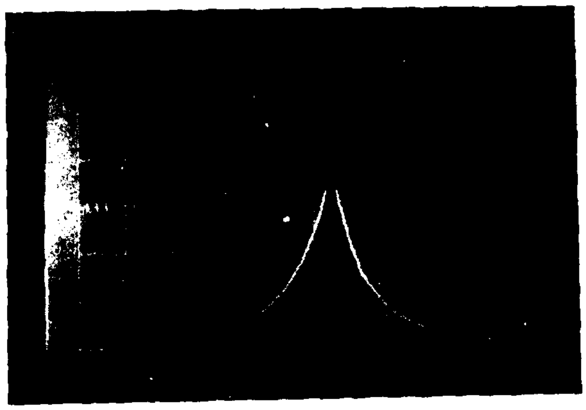
SHOT NUMBER: 6
PROPELLANT: N-1
CHARGE WEIGHT: 70 grams
DISKS: 2



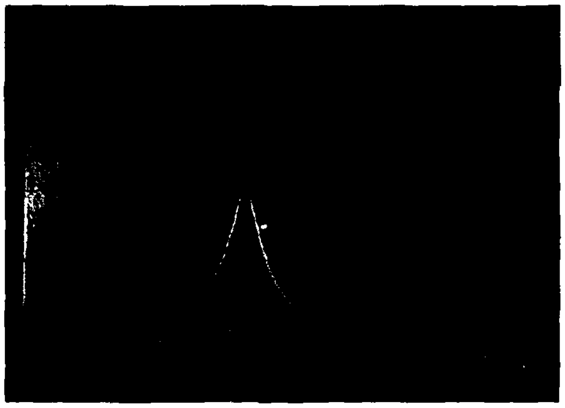
SHOT NUMBER: 7
PROPELLANT: TB-1
CHARGE WEIGHT: 74 grams
DISKS: 2



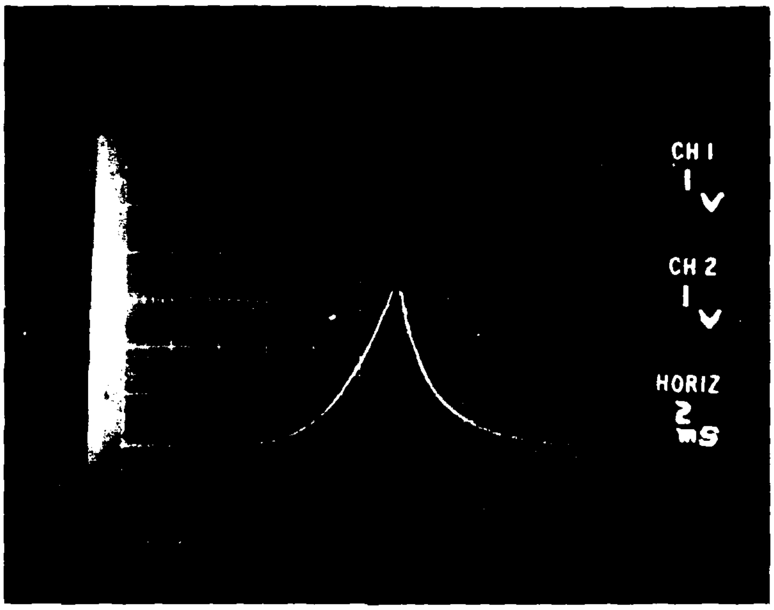
SHOT NUMBER: 23
PROPELLANT: DB-1
CHARGE WEIGHT: 75 grams
DISKS: 2



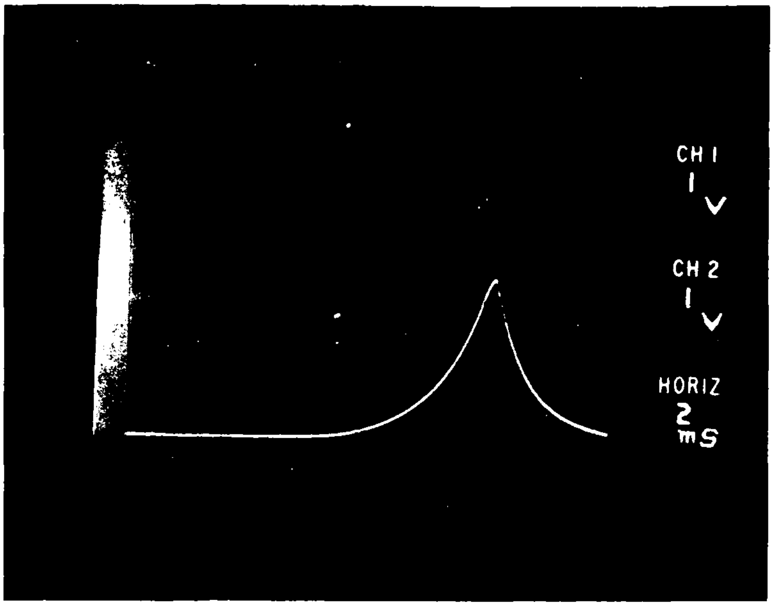
SHOT NUMBER: 43
PROPELLANT: N-2
CHARGE WEIGHT: 68 grams
DISKS: 2



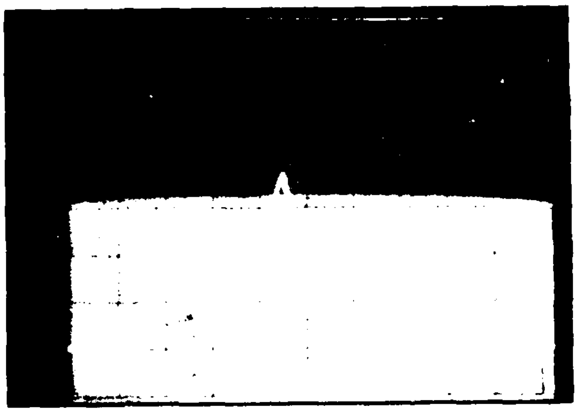
SHOT NUMBER: 44
PROPELLANT: DB-2
CHARGE WEIGHT: 73 grams
DISKS: 2



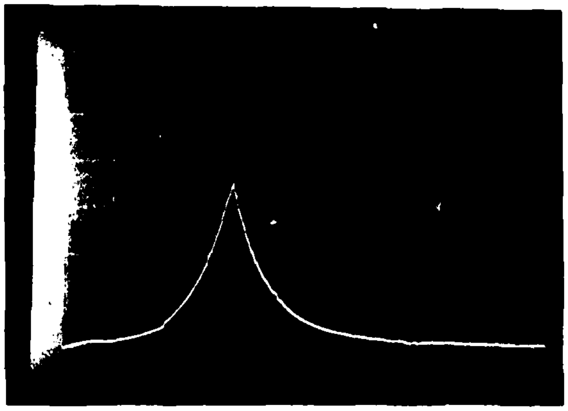
SHOT NUMBER: 54
PROPELLANT: TB-2
CHARGE WEIGHT: 71 grams
DISKS: 2



SHOT NUMBER: 99
PROPELLANT: PPL-A-6260 (HFP)
CHARGE WEIGHT: 66 grams
DISKS: 2

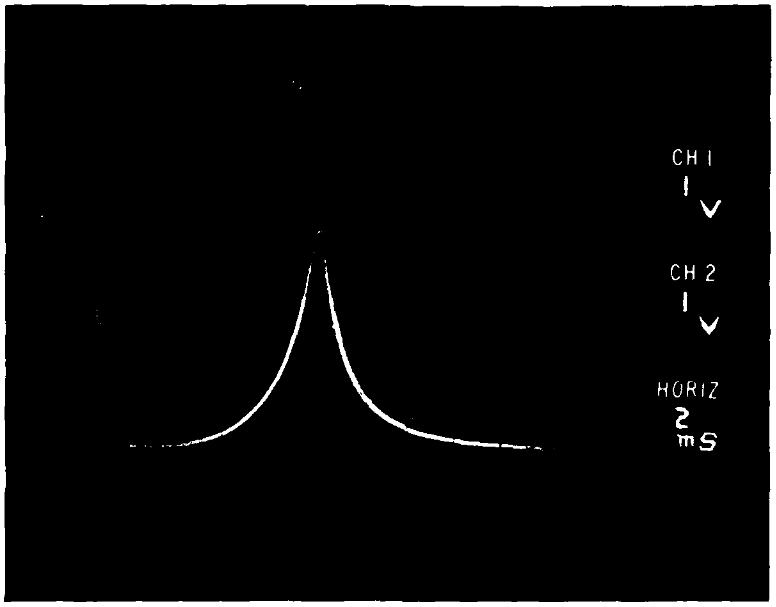


SHOT NUMBER: 106
PROPELLANT: TB-3
CHARGE WEIGHT: 69 grams
DISKS: 2

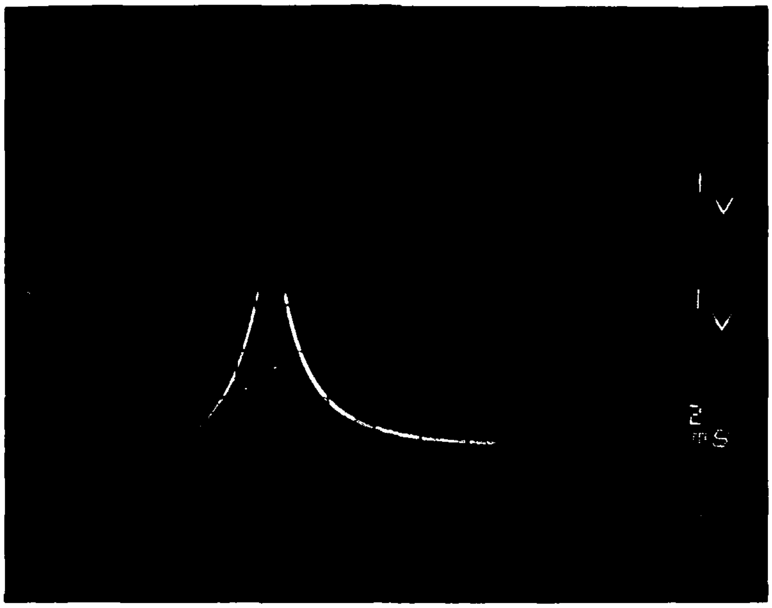


SHOT NUMBER 108
PROPELLANT: DB-3
CHARGE WEIGHT: 71 grams
DISKS: 2

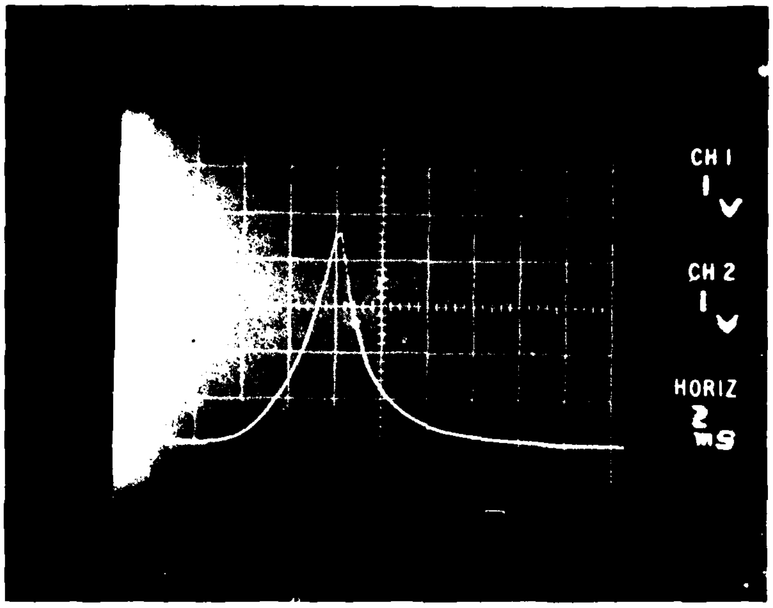
SHOT NUMBER: 116
PROPELLANT: N-3
CHARGE WEIGHT: 65 grams
DISKS: 2



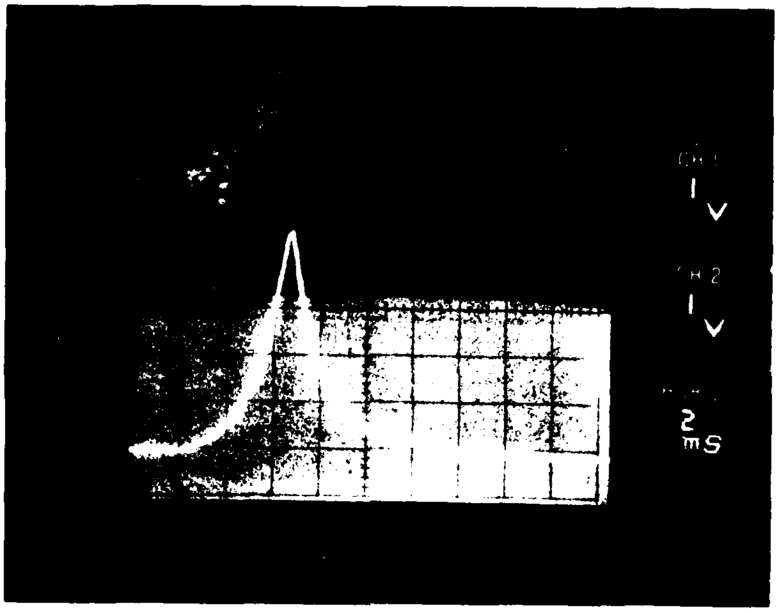
SHOT NUMBER: 155
PROPELLANT: N-2
CHARGE WEIGHT: 82 grams
DISKS: 3



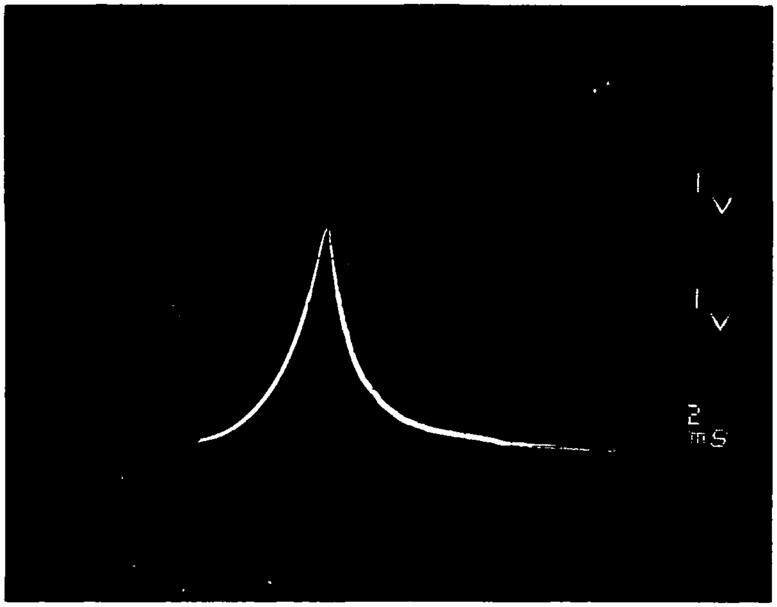
SHOT NUMBER: 156
PROPELLANT: DB-2
CHARGE WEIGHT: 85 grams
DISKS: 3



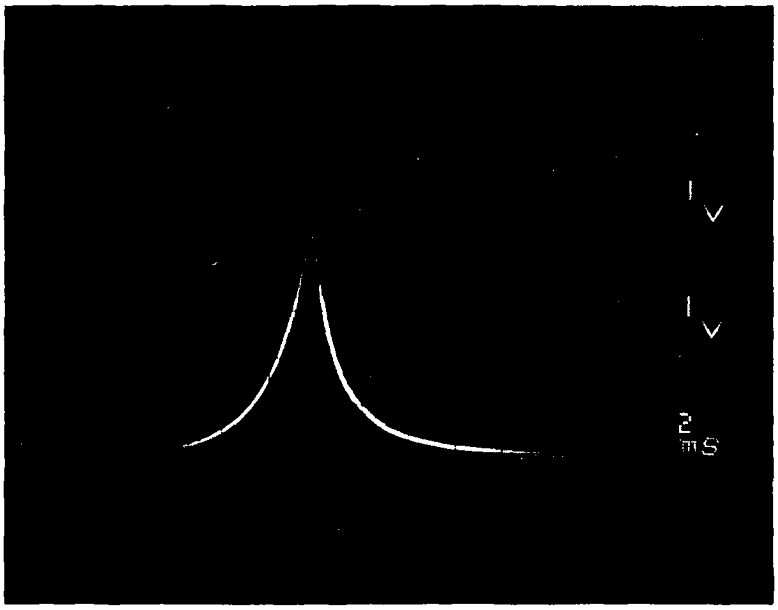
SHOT NUMBER: 160
PROPELLANT: TB-2
CHARGE WEIGHT: 87 grams
DISKS: 3



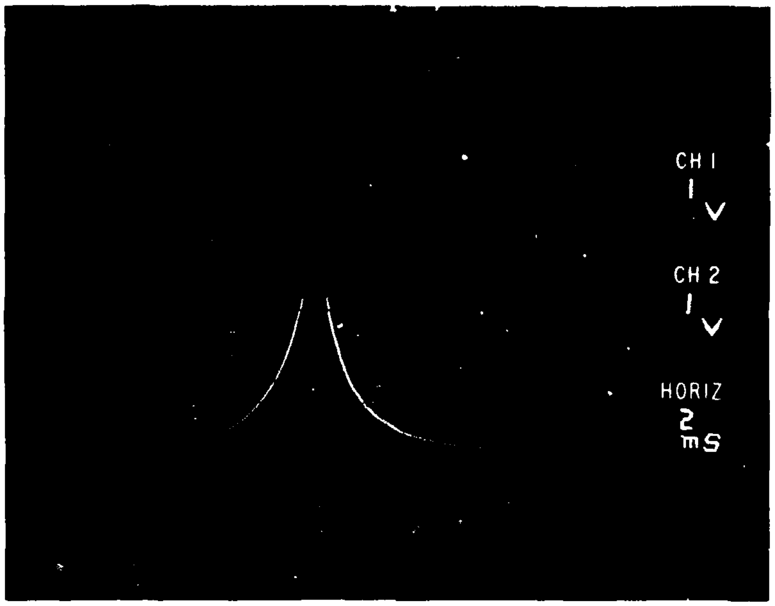
SHOT NUMBER: 168
PROPELLANT: DB-3
CHARGE WEIGHT: 87 grams
DISKS: 3



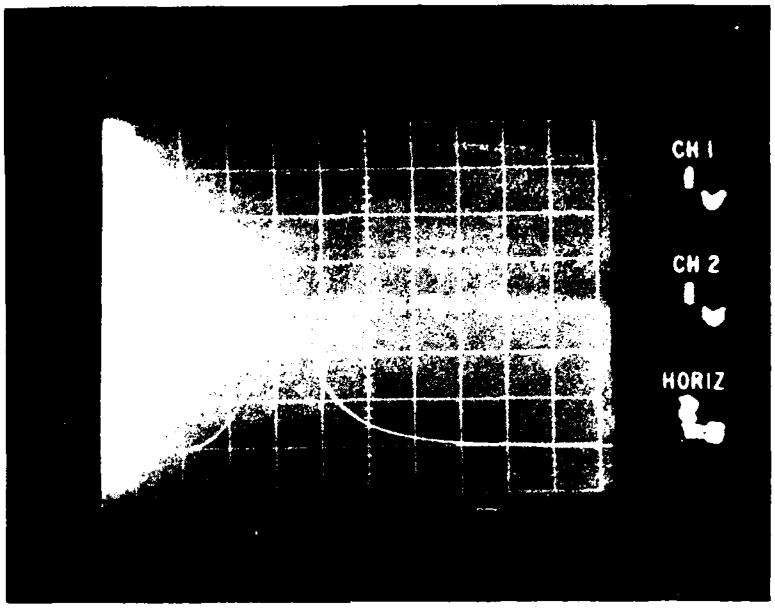
SHOT NUMBER: 169
PROPELLANT: TB-3
CHARGE WEIGHT: 84 grams
DISKS: 3



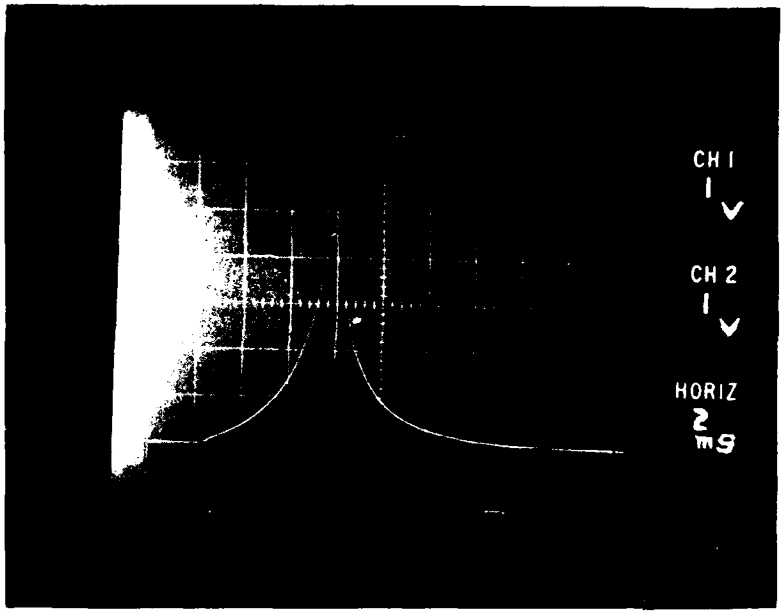
SHOT NUMBER: 170
PROPELLANT: N-3
CHARGE WEIGHT: 80 grams
DISKS: 3



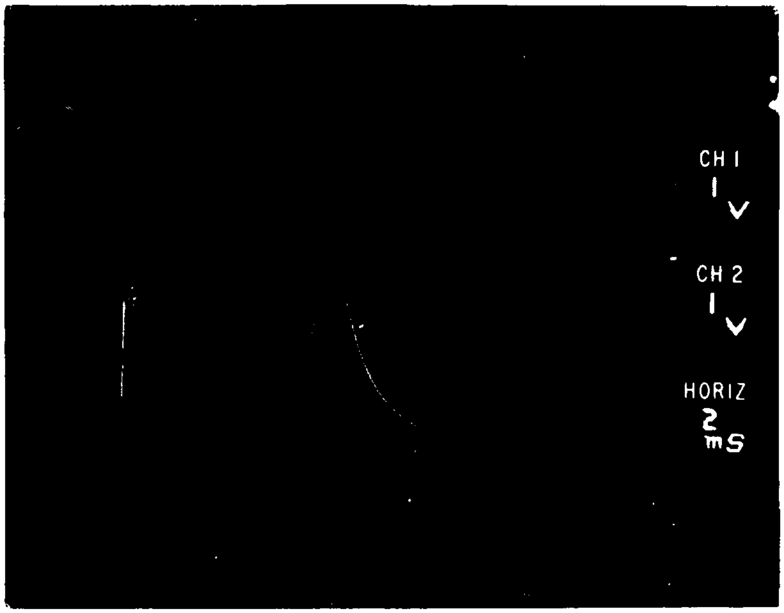
SHOT NUMBER: 182
PROPELLANT: X-1
CHARGE WEIGHT: 85 grams
DISKS: 5



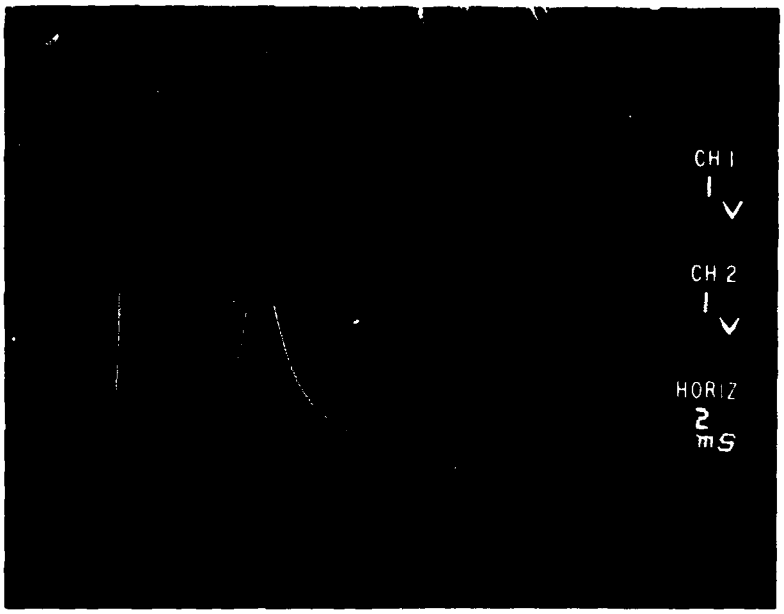
SHOT NUMBER: 184
PROPELLANT: TB-1
CHARGE WEIGHT: 90 grams
DISKS: 3



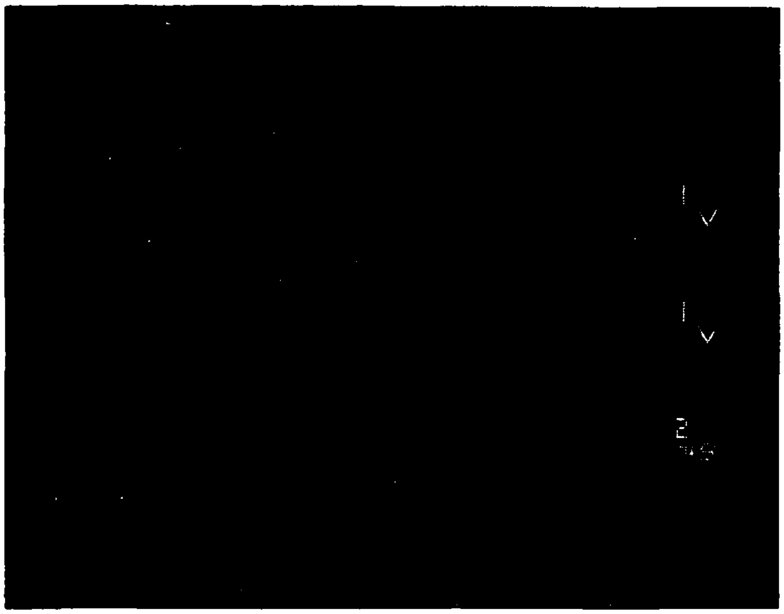
SHOT NUMBER: 186
PROPELLANT: DB-1
CHARGE WEIGHT: 91 grams
DISKS: 3



SHOT NUMBER: 196
PROPELLANT: RAD-PE-480-11 (M5)
CHARGE WEIGHT: 89 grams
DISKS: 3



SHOT NUMBER: 195
PROPELLANT: RAD 64592 (M5)
CHARGE WEIGHT: 89 grams
DISKS: 3



SHOT NUMBER: 200
PROPELLANT: R-29 (M30)
CHARGE WEIGHT: 86.4 grams
DISKS: 3

SHOT NUMBER: 201
PROPELLANT: M30C2
CHARGE WEIGHT: 93.8 grams
DISKS: 3

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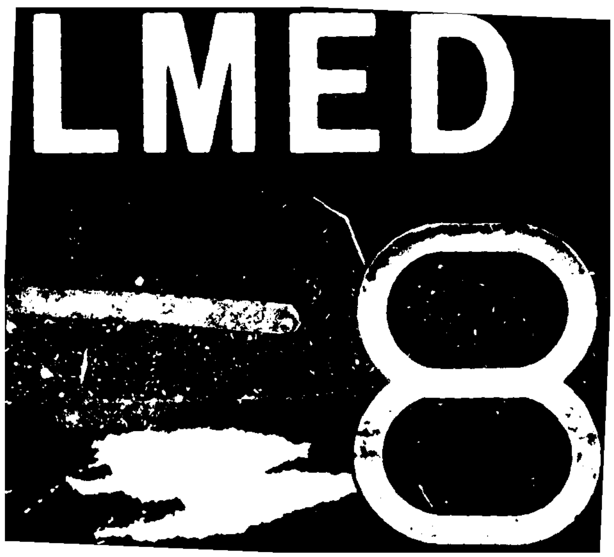
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